# Next-to-Next-to-Leading Order Soft Gluon Corrections in Top Quark Hadroproduction

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The discovery of the top quark in $p\bar{p}$ collisions at Run I of the Tevatron in 1995 and its observation currently at Run II, with expected increases in the accuracy of the top mass and cross section measurements, have made theoretical calculations of top production cross sections and differential distributions an interesting topical subject. The latest calculation of top hadroproduction includes next-to-next-to-leading-order (NNLO) soft-gluon corrections to the double differential cross section from threshold resummation techniques. Near threshold there is limited phase space for the emission of real gluons so that soft-gluon corrections dominate the cross section.

These soft corrections take the form of logarithms, $[\ln^l(x_{\rm th})/x_{\rm th}]_+$, with $l \le 2n-1$ for the order $\alpha_s^n$ corrections, where $x_{\rm th}$ is a kinematical variable that measures distance from threshold and goes to zero at threshold. NNLO calculations for top quark production have so far been done through next-to-next-to-leading-logarithmic (NNLL) accuracy, i.e. for the scale-independent terms, including leading logarithms (LL) with $l=3$, next-to-leading logarithms (NLL) with $l=2$, and NNLL with $l=1$. This NNLO-NNLL calculation has had great success in significantly reducing the factorization/renormalization scale, $\mu$, dependence of the cross section. However, the dependence of the corrections on the kinematics choice is substantial. In Ref. [1], the top cross section was studied in both single-particle-inclusive (1PI), where $x_{\rm th} = s_4/m^2$, and pair-invariant-mass (PIM), where $x_{\rm th} = 1 - M^2/s$, kinematics. (Here $s_4 = s + t_1 + u_1 > 0$ away from threshold, $m$ is the top quark mass and $M$ is the $t\bar{t}$ pair mass.) Important differences between the two kinematics choices were found, even near threshold. Thus subleading, beyond NNLL, contributions can still have an impact on the cross section. If all the NNLO soft corrections are included, there should be no difference between the two kinematics near threshold. If all NNLO corrections were known, there should be no difference between the two kinematics, even far from threshold. Away from threshold, where the approximations of Ref. [1] are not expected to apply since real gluon emission comes into play, the discrepancy between the 1PI and PIM results is not surprising. However, the NNLO-NNLL calculation exhibits some notable discrepancies between the two kinematics even at the lowest $\eta$, where $\eta = s/4m^2 - 1 \to 0$ at threshold. Thus, additional subleading terms are clearly needed to bring the calculation under further theoretical control.

Here, we include additional subleading NNLO soft corrections, including next-to-next-to-next-to-leading logarithms (NNNLL), as well as some virtual $\delta(x_{\rm th})$ corrections. We apply master formulas for the NNLO soft and virtual corrections. These subleading corrections bring the 1PI and PIM results into agreement near threshold for both the $q\bar{q} \to t\bar{t}$ and the $gg \to t\bar{t}$ channels. The discrepancies away from threshold are diminished, especially in the $gg$ channel [2].

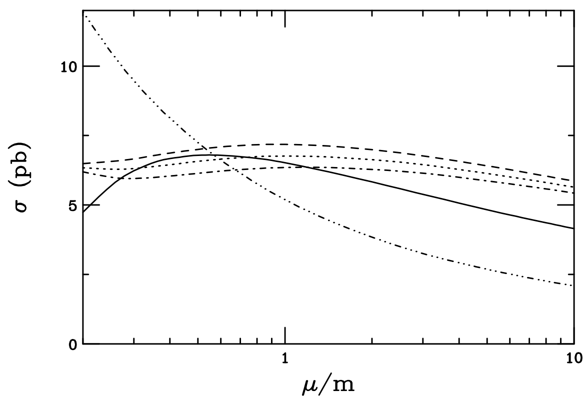


FIG. 1: The scale dependence of the $t\bar{t}$ total cross sections in $p\bar{p}$ collisions at $\sqrt{S} = 1.96$ TeV as a function of $\mu/m$. The LO (dot-dot-dot-dashed), NLO (solid), and approximate NNLO-NNNLL+$\zeta$ 1PI (dashed), PIM (dot-dashed) and average (dotted) results are shown.

We use the recent MRST2002 NNLO (approximate) parton densities with an NNLO evaluation of $\alpha_s$. We present the cross sections as functions of $\mu/m$ for $0.2 < \mu/m < 10$ at $\sqrt{S} = 1.96$ TeV and $m = 175$ GeV in Fig. 1. The NLO cross section is not as strong a function of $\mu/m$ as the LO cross section. The NNLO-NNNLL+$\zeta$ cross sections, however, approach the independence of scale corresponding to a true physical cross section. They change by less than 15% over the entire range of $\mu/m$ shown. The change in the NNLO-NNNLL+$\zeta$ cross sections through the range $m/2 < \mu < 2m$, normally displayed as a measure of scale uncertainty, is less than 3%. Note also that, at this energy, the absolute difference between the NNLO-NNNLL+$\zeta$ 1PI and PIM cross sections is also not large.

[1] N. Kidonakis, E. Laenen, S. Moch, and R. Vogt, Phys. Rev. **D64**, 114001 (2001).
[2] N. Kidonakis and R. Vogt, Phys. Rev. **D68**, 114014 (2003).